NBSIR 84-2859

The NBS Daylight Availability Database

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Building Physics Division
Gaithersburg, Maryland 20899

July 1984

Prepared for

Naval Civil Engineering Laboratory
Port Hueneme, California 93043

National Fenestration Council
3310 Harrison St.
Topeka, KS 66611

Naval Facilities Engineering Command
U.S. Navy
Washington, DC 20390

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report presents a database containing hourly measurements of solar radiation, illumination, sky luminance and ambient air temperature for an entire composite year. The measurements were made at the National Bureau of Standards, Gaithersburg, Maryland (77° west longitude, 38°5 north latitude). Both instantaneous hourly and integrated average hourly measurements are included, as are daily, monthly and annual averages and totals. For each measured quantity, a histogram of the distribution of the data is presented for the year. The data measurement, collection and analysis system is described.

Key words: daylight availability, irradiance, luminance, sky illuminance, solar radiation, weather data

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1. INTRODUCTION

Weather data has been collected and compiled at many locations, for many years. Such information is used for a variety of purposes, including weather predictions, aviation and agricultural forecasts. However, building designers need special types of weather data to evaluate the thermal and energy performance of buildings. Information regarding solar radiation, daylight illumination and outdoor air temperature is essential for the effective analysis of building envelopes, the optimum use of fenestration, and accurate analyses of building energy performance. In some instances, typically for worst-case or design day purposes, single values are used for the pertinent weather parameters. Examples of this would be a minimum or average outdoor air temperature to calculate heat transfer through a portion of a building envelope or calculating interior daylight levels assuming an overcast sky. While single-valued weather data are useful, accurate analysis of building energy performance and optimum design of building components requires data which describes the dynamic nature of weather parameters over an annual period. Hourly data is frequently sufficient for this purpose.

Most standard weather stations collect a limited menu of climatic parameters, some including global total solar irradiance on a horizontal surface, outdoor air temperature, relative humidity, barometric pressure, wind speed and amount of cloud cover [1]. These weather data are available from the National Climatic Center [2] and various other sources including computer time-sharing services. The standard weather data sources lack some detailed information required for building design, such as data for radiant and visible energy incident upon horizontal and vertical surfaces, luminance distribution of the sky dome, and measurements of cloud conditions. In particular, sky luminance and illuminance data are required for calculating interior daylight levels, and vertical irradiance data is required for determining fenestration heat transfer. Only by considerating the heating, cooling and lighting effects of fenestration options can building designers determine the most effective utilization of fenestration.

This report contains a record of irradiance, sky illuminance, luminance and outdoor air temperature measurements over a one-year period. Twenty eight climate and solar parameters are presented on an hourly basis. Two groups of data are presented: integrated average hourly data and the corresponding instantaneous hourly data. Also included are daily totals and averages, monthly averages and annual averages. For each measured quantity, a histogram of the distribution of the data is presented for the year.

The majority of the data was collected during 1982, however entire days with missing data due to equipment failure have been replaced with data from the same date from either 1981, 1983, or 1984. The measurements were made at the Daylight Laboratory, National Bureau of Standards, Gaithersburg, Maryland (suburb of Washington, D.C.), 77° west longitude 38°5' north latitude (see figure 1.).

The following sections describe the measured parameters, data measurement and analysis system, followed by the database.

2. DESCRIPTION OF MEASUREMENTS

2.1 MEASURED PARAMETERS

Measurements were made of diffuse and global irradiance, and diffuse and global illuminance on a horizontal surface, global irradiance and illuminance on vertical surfaces (north-, south-, east- and west-facing), sky luminance at five locations (15° solid angle spots), and exterior air temperature. Table 1 describes the sensors used for the measurements. A complete list of the measured parameters, sensor types and related information is shown in table 2.

It should be noted that the alphanumenic codes associated with each measured parameter do not correspond to any particular nomenclature but rather are taken directly from the names of the FORTRAN variables used for data processing. This provides for consistency among the equations in the text of the report and the printout of the database. FORTRAN is limited to upper-case variable names, with no provisions for subscripts. Table 2 includes a description of each measured parameter and the associated code.

A general description of sensor types and characteristics follows.

a) Sky Luminance - Luminance is the luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction. Luminance was measured using photovoltaic silicon cells, with photometric filters and 15° solid angle field-of-view. One sensor was centered on zenith (LZ) and each of four other sensors was centered at 42° elevation, due north (LN), east (LE), south (LS) and west (LW). A photograph of the luminance sensor array is shown in figure 3.

b) Illuminance - Illuminance is the density of luminous flux (weighted by eye response) incident on a surface. Illuminance was measured using photovoltaic silicon cells, with photometric filters and cosine diffusers. Global illuminace (IZ) was measured on a horizontal surface from an unobstructed sky hemisphere. Diffuse illuminance (ID) on a horizontal surface was measured using a shading band (see figure 3). Corrections for the portion of sky obstructed by the shading band were made using manufacturer's data. Direct normal illuminance (IBN) was determined by subtracting diffuse from global illuminance and dividing by the sine of the solar altitude,

$$\mathrm{IBN} = \frac{\mathrm{IZ-ID}}{\sin\,(\mathrm{SALT})} \tag{1}$$

where

SALT = solar altitude

$$\mathrm{SALT} = \arcsin\,[\sin L \sin D + \cos L \cos D \cos\,(12-T)15] \tag{2}$$

L = site latitude

$$D = \text{solar declination} = 0.4093 \sin\,[\tfrac{2\pi}{365}\,(J+284)] \tag{3}$$

Table 1. Sensor Types

Type A)	Luminance - Photovoltaic silicon cell with 15° solid angle lens and photometric filter (which follows the standard spectral eye response curve [3])
Type B)	Irradiance - Photovoltaic silicon cell with cosine corrected diffuser and radiometric filter (flat response 450-950 nm spectral range), hemispherical field-of-view
Type C)	Illuminance - Photovolatic silicon cell with cosine corrected diffuser and photometric filter, hemispherical field-of-view
Type D)	Irradiance - Pyranometer, thermopile type (flat response 300-3000 nm spectral range), hemispherical field-of-view
Type E)	Temperature - Copper-constantan thermocouple, with radiation shield

Table 2. List of Database Parameters

	Code	Parameter	Sensor Type*	Measurement+ Units	Maximum Uncertainty
1	LZ	Zenith luminance	A	cdm^{-2}	$\pm$ 3%
2	LN	North luminance	A	cdm^{-2}	$\pm$ 3%
3	LE	East luminance	A	cdm^{-2}	$\pm$ 3%
4	LS	South luminance	A	cdm^{-2}	$\pm$ 3%
5	LW	West luminance	A	cdm^{-2}	$\pm$ 3%
6	SALT	Solar altitude	-	degrees	-
7	SAZ	Solar azimuth	-	degrees	-
8	STIM	Solar time	-	hours	-
9	SN	North vertical irradiance	B	wm^{-2}	$\pm$ 8%
10	SS	South vertical irradiance	B	wm^{-2}	$\pm$ 8%
11	SE	East vertical irradiance	B	wm^{-2}	$\pm$ 8%
12	SW	West vertical irradiance	B	wm^{-2}	$\pm$ 8%
13	IZ	Global horizontal illuminance	C	lux	$\pm$ 3%
14	IS	South vertical illuminace	C	lux	$\pm$ 3%
15	IE	East vertical illuminance	C	lux	$\pm$ 3%
16	IW	West vertical illuminance	C	lux	$\pm$ 3%
17	IN	North vertical illuminance	C	lux	$\pm$ 3%
18	ID	Diffuse horizontal illuminance	C	lux	$\pm$ 5%
19	SRT	Global horizontal irradiance	D	wm^{-2}	$\pm$ 4%
20	SRD	Diffuse horizontal irradiance	D	wm^{-2}	$\pm$ 6%
21	CR	Cloud ratio	-	-	$\pm$10%
22	TO	Ambient air temperature	E	°F	$\pm$ 0.8°F
23	IBN	Direct normal illuminance	-	lux	$\pm$ 8%
24	SBN	Direct normal irradiance	-	wm^{-2}	$\pm$10%
25	E1	Atmospheric extinction coefficient 1	-	-	-
26	E2	Atmospheric extinction coefficient 2	-	-	-
27	TR1	Downward transfer ratio 1	-	-	-
28	TR2	Downward transfer ratio 2	-	-	-

* From Table 1.

+ cdm^{-2} = candelas per square meter
Wm^{-2} = watts per square meter
lux = lumens per square meter

J = Julian Date $1 \leq J \leq 365$
T = Solar time.

Illuminances on vertical planes (north, east, south and west) were measured using an array shielded from ground reflections (see figure 4).

c) Irradiance - Irradiance is the density of radiant flux (equally weighted for all wavelengths) incident on a surface. Global irradiance (SRT) on a horizontal surface was measured using a thermal-type pyranometer exposed to the unobstructed sky dome (see figure 5). Diffuse irradiance (SRD) was measured with a similar instrument and a shading band. Corrections for the portion of the sky obstructed by the shading band were made using manufacturer's data. Direct normal irradiance (SBN) was also determined by subtracting diffuse from global irradiance and dividing by the sine of the solar altitude.

$$SBN = \frac{SRT - SRD}{\sin(SALT)} \tag{4}$$

d) Air temperature - Outdoor air temperature was measured using a type-T (copper-constantan) thermocouple, with a radiation shield.

The database also contains the derived quantities of solar altitude, solar azimuth, solar time, atmospheric extinction coefficient and downward transfer ratio. Figure 6 shows the definitions of the solar angles.

e) Solar altitude - Calculated using equation 2.

f) Solar azimuth - Calculated using equation 5a, b, or c.

$$W = (12-T) \times 15 \tag{5}$$

If $\cos W < \tan D/\tan L$

$$SAZ = \arcsin(\cos D \sin W/\cos SALT) \tag{5a}$$

If $\cos W > \tan D/\tan L$

$$SAZ = \pi - \arcsin(\cos D \sin W/\cos SALT) \tag{5b}$$

$$\text{If } SAZ < 0,\ SAZ = SAZ + 2\pi \tag{5c}$$

Solar azimuth is zero due north, 90° due east, 180° due south, and 270° due west.

g) Solar time - Calculated from equation 6.

$$STIM = TS + (1 \text{ if daylight time}) + ET - 2/15 \tag{6}$$

where TS = standard time (decimal hours)
ET = equation of time

$$= 0.170 \sin \frac{4\pi}{373} (J-80) - 0.129 \sin \frac{2\pi}{355} (J-8) \quad (7)$$

h) <u>Cloud ratio</u> = The ratio of diffuse to global irradiance.

$$CR = \frac{SRD}{SRT} \quad (8)$$

i) <u>Atmospheric extinction coefficent</u> - Two versions (E1,E2) were determined from measurements, based on direct illuminance or irradiance, as follows:

E1 (direct illuminance)

$$E1 = - \sin (SALT) \ln \frac{IBN}{IXT} \quad (9)$$

where $IXT = 127,500 \left\{ 1 + 0.034 \cos \frac{2\pi}{365} (J-2) \right\}$ (10)

E2 (direct irradiance)

$$E2 = - \sin (SALT) \ln \frac{SBN}{SXT} \quad (11)$$

where $SXT = 1353 \left\{ 1 + 0.034 \cos \frac{2\pi}{365} (J-2) \right\}$ (12)

j) <u>Downward transfer ratio</u> - Two versions (TR1 and TR2) were computed, one from irradiance and one from illuminance. The downward transfer ratio is defined as the portion of solar energy scattered out of the direct beam reaching the ground [7]. Therefore one minus the downward transfer ratio is reflected back into space, or absorbed by the atmosphere.

TR1 (illuminance)

$$TR1 = \frac{ID}{IXT \sin(SALT)[1-EXP(-E1/\sin(SALT))]} \quad (13)$$

TR2 (irradiance)

$$TR2 = \frac{SRD}{SXT \sin(SALT)[1-EXP(-E2/\sin(SALT))]} \quad (14)$$

2.2 MEASUREMENT SYSTEM

The data acquisition system consisted of a microcomputer-controlled data logger which monitored the measurement sensors. All sensors were configured to provide voltage inputs to the data logger, which performed analog-to-digital conversion and voltage measurement. The data logger also provided temperature compensation for the thermocouple readings. Under control of the microcomputer, sensor

readings were continuously and sequentially scanned. At the beginning of each hour, a data file for that hour was assembled consisting of the current reading for each sensor (instantaneous value) and the average of all the readings for each sensor over the previous one hour period (average value). Each average value is calculated from fifteen readings during the hour. The letter "A" preceding a measured parameter name indicates an average value.

Data were stored on 0.133 m (5.25 in.) floppy disks, and transferred to a larger computer for subsequent processing, analysis and storage.

2.3 DATA ANALYSIS AND CHECKING

The database contains measurements of eighteen parameters, and ten derived quantities. Over the period of a year, this amounts to approximately 2.5 million readings, including average and instantaneous values. Each annual average parameter is a result of 131,400 readings, and each instantaneous parameter is represented by 8760 readings. The initial raw data files were processed to check for errors and inconsistencies. A careful review of the data was conducted to identify erroneous data, however, data were only removed from the database if a clear justification, as described below could be made for such removal. Consequently, if a datum passed all the checking routines and was not associated with any known measurement problems, it was included in the database. Even though the checking routines were considered a successful technique for controlling erroneous data, from time to time questionable data still appeared and were flagged accordingly. The shear volume of data processed could have resulted in a small portion of inaccurate data remaining in the database undetected.

Potential inaccuracies can be grouped into two general categories. The first category includes what could be described as measurement errors. In this category would fall calibration errors, sensor non-linearity and errors in voltage measurement or analog-to-digital conversion. The second category includes measurements which are accurate, but not measuring the parameter of interest properly. Prime examples of this would be a sky luminance measurement when the solar disk is visible in the field of view of the luminance sensor, or when snow is present on sensors. In these cases, the measurement system may be working properly, but the reading would not be representative of sky luminance as assumed.

The first stage of data checking included adjusting each reading for any zero offset, setting to zero any slight non-zero readings known to be zero (i.e., irradiance after dark), and setting diffuse irradiance and illuminance equal to total irradiance and illuminance, respectively, if the respective diffuse component reading exceeded the reading for total. This second correction is occasionally necessary on overcast days due to the average nature of the shading band correction factor, but is usually a small effect.

The second stage of data checking involved comparing each reading to an acceptable range for each parameter, and intercomparing related readings as a group. Maximum and minimum levels were established for each parameter, based on the expected range of theoretically possible readings. Readings outside of

this range were flagged with an asterisk (*) and set to 999999. For the luminance channels, a reading in excess of 15,000 cdm^{-2} was assumed to be due to interference from the solar disk, and therefore flagged with an asterisk but not set to 999999 unless the reading exceeded 75,000 cdm^{-2}. Three groups of parameters were assembled for intercomparison. The five luminance sensors were one group, the four vertical irradiance sensors the second group and the four vertical illuminance sensors the third group. Within each group an average of each hour's readings was computed, and if any individual reading differed from the average by more than a factor of ten (or 1/10) that reading was flagged with a plus sign (+) and set to 999999.

The averaged hourly data should be more accurate than the instantaneous hourly data for two reasons. First, any random errors (electronic noise, analog to digital conversion, etc.) should cancel out when multiple readings are averaged. Second, an occasional false reading due to intermittent malfunctions or conditions will have a small effect on the average reading. Both instantaneous and average readings are of value. In many daylighting applications, the instantaneous conditions are of interest. However, a one hour average is nearly "instantaneous" in relation to an annual file containing 8760 hourly readings. Since many energy calculations are done on an hourly basis, perhaps hourly averaged daylighting data are appropriate to use for these applications.

When data were unavailable for 1982, due to equipment down time, data were substituted from 1983, 1984 or 1981 for the same julian date. While this changes the distribution of the data and affects the average slightly, the usefulness of the annual data is not compromised, since 1982 should not be considered a special year. Thus, the database reflects reasonable conditions for a possible year, but not necessarily a typical year.

3. DISCUSSION OF DATABASE

The primary objective of the publication of this database is to provide a comprehensive set of reference, concurrent measurements of illuminance, irradiance and sky luminance for a one-year period. These data are critically needed for building design purposes and daylighting analyses, but are virtually unavailable.

All or portions of the database might be used as driving parameters for energy or daylighting calculations, or for other purposes such as sky and solar modeling. Detailed analysis of the relationships between the measured parameters, or their dynamic behavior, may enable new correlations to be developed for improved sky and solar modeling. Since the annual database contains such a vast quantity of information, it would be useful to analyze the hourly data and determine means to characterize the measurements in a more general manner.

Two methods were used to characterize and summarize the measurements. One method involved computing averages for each of the parameters on a daily, a monthly and an annual basis. The second method consisted of determining the mean and standard deviation of each parameter and plotting a histogram showing the distribution of the data over the year.

The computed averages of each parameter provide a means for making an assessment of the general magnitude of that parameter, and allow comparison of different day's data. For example, a very bright day will have a much higher average illuminance than a dark overcast day. In addition to the daily average for each parameter, which is computed using only the non-zero readings, the daily total of each measured parameter was tabulated. This quantity indicates the total of all readings for each parameter, thereby including the effects of longer or shorter daylight periods throughout the year. Note that averages based on 24 hours can easily be computed by dividing each daily total by 24.

Monthly averages were also calculated for each parameter. The monthly average is defined as the average daily total for the month (not the average hourly reading). Annual averages were calculated for each parameter, being equal to the average daily total for the year and the hourly average of non-zero readings. Exceptions to the above criteria were required for the atmospheric extinction coefficients and downward transfer ratios, since a total atmospheric extinction coefficient for the day would have no meaning. Here only hourly averages for each month and the annual average were tabulated.

While the daily, monthly and annual averages provide much useful information, they do not give an indication of the variability or distribution of the values of each parameter. An effective way of presenting the distribution of each parameter is through a histogram of the readings showing the percentage of the entire annual data set falling into various intervals. Such histograms were developed from the data to show the spread of the readings for each parameter, along with the probability of an individual reading falling within a certain range. The mean and standard deviation of the annual set of data for each

parameter were also calculated. For this usage, the standard deviations do not represent an uncertainty, but rather indicate the variability of each parameter throughout the year.

Before discussing the individual histograms, a general examination of the dynamic nature of the database parameters is appropriate. The behavior of each of the parameters through the year is governed by the superposition of several cycles. The irradiance, illuminance and luminance data follow a strong diurnal (daily) cycle in which maximum values typically occur near a certain set of solar angles. For example, energy incident on east-facing vertical surfaces is typically maximum in the morning, while horizontal and south-facing surfaces typically receive maximum incident energy at solar noon. However, this does not mean that south vertical irradiance is always maximum at solar noon, since considerable hourly variations can occur due to a randomly fluctuating cycle superimposed on the diurnal cycle. This random cycle is a function of the local weather conditions as influenced by cloud cover, atmospheric water vapor and other factors. A third significant cycle is due to seasonal effects. Many geographical locations exhibit observable differences in available solar radiation or cloud conditions on a seasonal basis, whereby more overcast days occur in winter than in summer (or vice versa). Outdoor air temperature follows a strong seasonal cycle and a strong diurnal cycle. Direct normal irradiance and illuminance are less sensitive to a daily cycle, except for the effects of low solar elevations.

3.1 DATA DISTRIBUTION HISTOGRAMS

A pair of histograms is presented for each parameter, the first based on instantaneous readings, the second based on average readings. Figures 7 through 11 present the distribution of readings for each of the sky luminance sensors. Sky luminance shows a wide range in the data, but a fairly narrow band of probable intensity. Readings greater than 15,000 cdm^{-2}, which are due to the solar disk being present in the luminance measurement area, are excluded from these figures.

Figures 12 through 15 present the distribution of vertical irradiance readings. As would be expected, north vertical irradiance is significantly lower than the other vertical planes averaging only one third of south vertical irradiance. East and west vertical irradiances are about two thirds of the south vertical readings.

Figures 16 through 21 present the distribution of the illuminance readings. Considerable variation is apparent for all surfaces, graphically illustrating the wide dynamic range of daylight availability. Diffuse horizontal illuminance and east, south and west vertical illuminance range from 66 to 50 percent of global horizontal illuminance, while north vertical is less than 25 percent.

The distributions global horizontal irradiance and diffuse horizontal irradiance are presented in figures 22 and 23, respectively. Diffuse irradiance average about 50 percent of global irradiance. The ratio of diffuse to global irradiance, cloud ratio, is shown in figure 24. The average cloud ratio was 68 percent, but a wide range occurred.

Figure 25 shows the distribution of outdoor air temperatures. The mean air temperature was 10.6 C (51.1°F).

Direct normal illuminance and irradiance are presented in figures 26 and 27, respectively. They exhibit a fairly even distribution. The computed atmospheric extinction coefficients are shown in figures 28 and 29. Over half of the readings were less than one or greater than 5.75. The downward transfer ratios are presented in figures 30 and 31. TR1 (illuminance) averages 36 percent, while TR2 (irradiance) averages 31 percent.

3.2 DATABASE PRINTOUT

Appendix A contains the printout of the daylighting database. Each parameter is labeled with an alpha code as listed in table 2. One day's worth of data is on each page, with adjacent pages containing hourly average data for the day, and instantaneous hourly data for the day. The julian date and calendar date are listed at the top of each page. Each page is divided into two sections with twelve hour's data in each section. Hours are indicated by column headings. The units of measurement are listed, along with daily totals and non-zero averages for each parameters. The last page of the appendix contains the daily or hourly averages (as appropriate) on a monthly and annual basis, for each parameter.

Missing or defective data were represented by 999999. Uncertain or questionable data were flagged with an asterisk (*) or plus sign (+). No attempt was made to synthesize replacement data for missing or bad data, because the intent of this paper is to provide measured data, rather than calculated. However, the user can use whatever means they feel is appropriate to fill in for missing data. Procedures such as interpolating between available data points [1], or calculating based on other parameters [4] or models [5,6] would be useful for that purpose.

4. SUMMARY

An annual database is presented including irradiance, illuminance, sky luminance, sky condition and temperature measurements. The database is intended for use in daylighting design and calculations, building energy analyses, and sky and solar modeling. The measurement system is described. The data is analyzed and processed including examination of reading averages, distribution and variability over a one year period.

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Figure 1. NBS Daylighting Laboratory

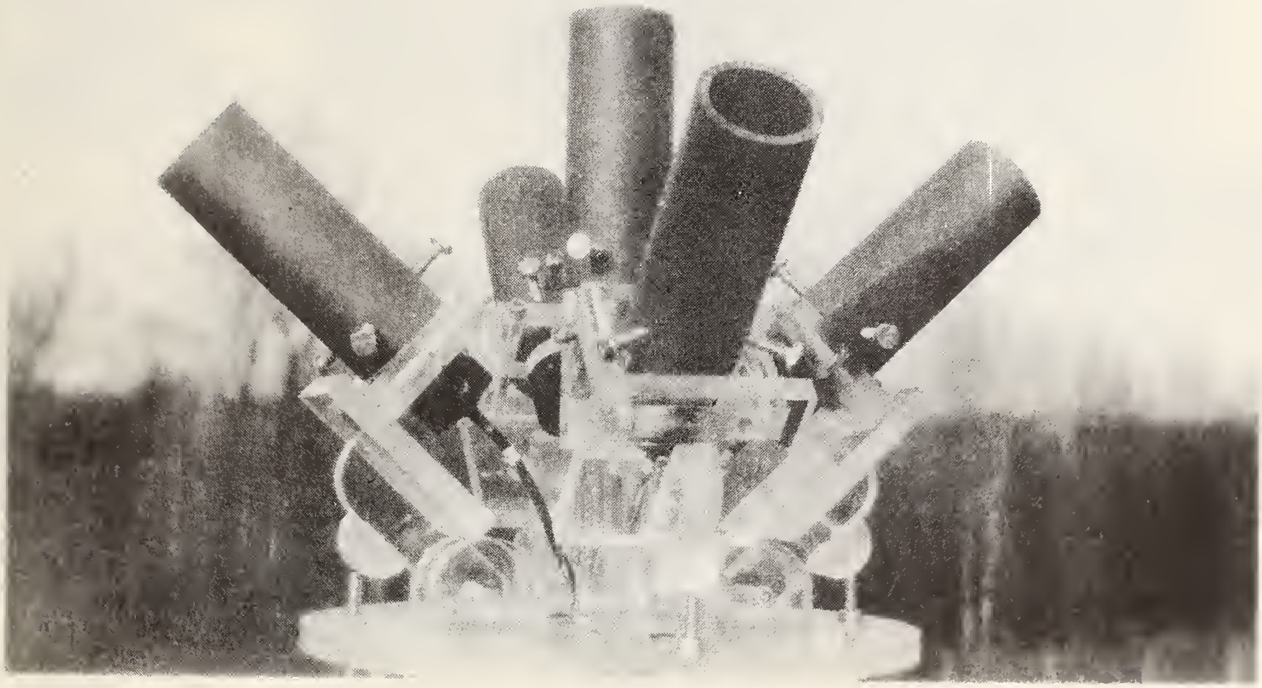

Figure 2. Luminance sensor array

Figure 3. Diffuse illuminance and irradiance sensors

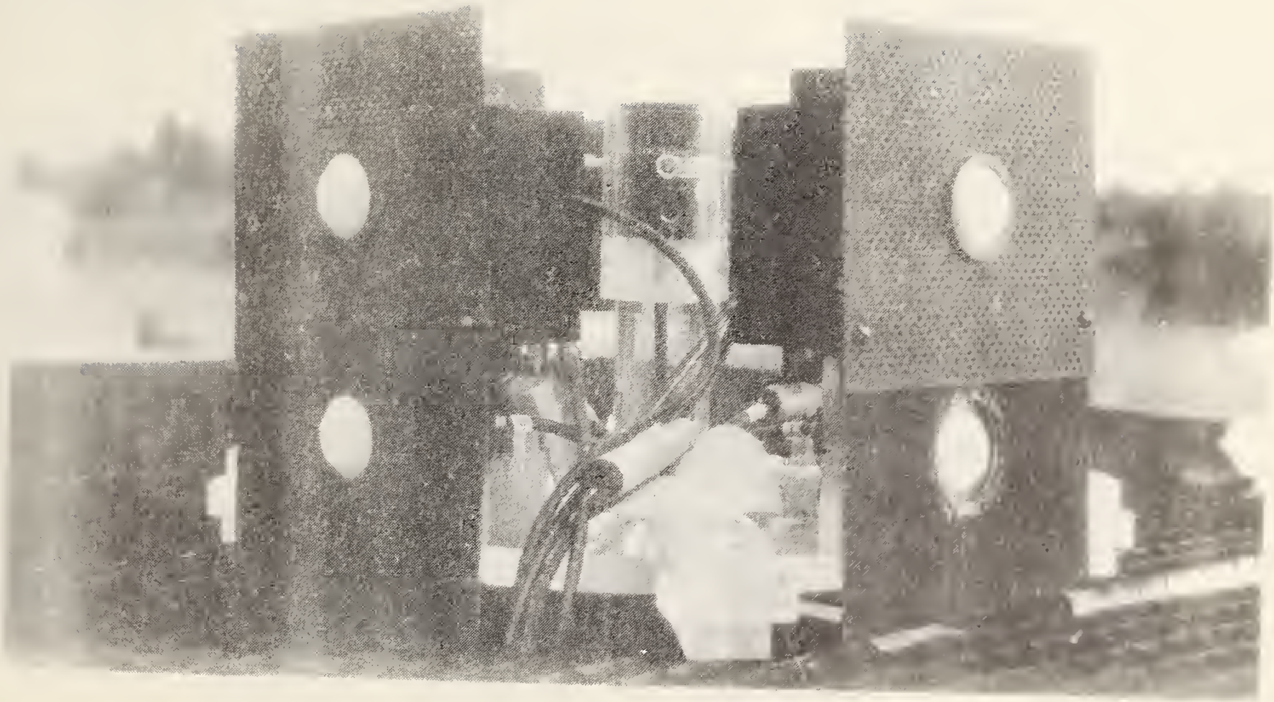

Figure 4. Vertical illuminance and irradiance sensors ......

Figure 5. Global irradiance sensor

a_t=solar altitude

a_s=solar azimuth

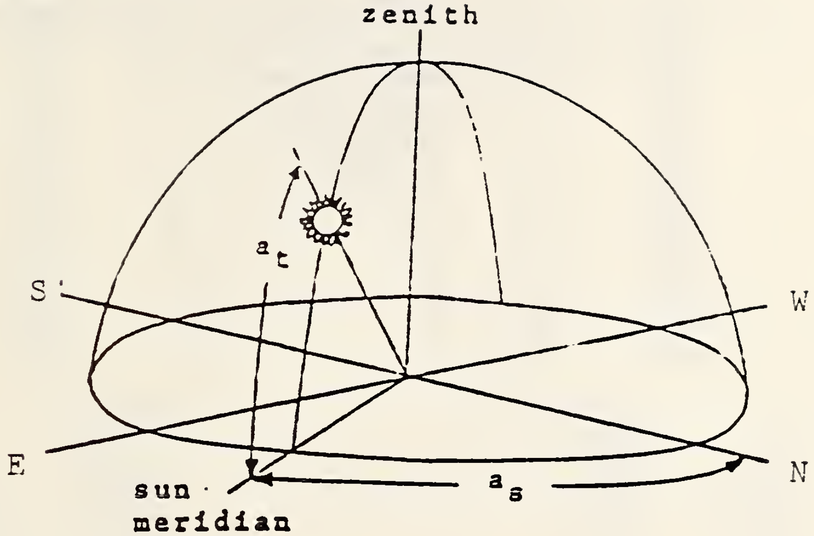

Figure 6. Definitions of solar angles

```
AV. LZ
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
        0      638      ********************************
     1000      768      ***************************************
     2000      604      *******************************
     3000      435      **********************
     4000      335      *****************
     5000      253      *************
     6000      210      ***********
     7000      141      ********
     8000      123      *******
     9000      114      ******
    10000       77      ****
    11000       69      ****
    12000       55      ***
    13000       57      ***
    14000       29      **
    15000       11      *

          AV. LZ
N           3917
MEAN      3492.3
MEDIAN    2418.5
TMEAN       3183
STDEV     3349.7
SEMEAN        54
MAX        14939
MIN          .05
Q3          5154
Q1           915

IN. LZ
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
        0      646      *********************************
     1000      796      ****************************************
     2000      634      ********************************
     3000      420      *********************
     4000      307      ****************
     5000      246      *************
     6000      211      ***********
     7000      125      *******
     8000       92      *****
     9000       95      *****
    10000       75      ****
    11000       65      ****
    12000       51      ***
    13000       41      ***
    14000       35      **
    15000       18      *

          IN. LZ
N           3861
MEAN      3350.2
MEDIAN    2244.2
TMEAN       3023
STDEV     3313.5
SEMEAN        53
MAX        14983
MIN         2.03
Q3          4861
Q1           897
```

Figure 7. Data distribution histogram for zenith luminance (LZ)

```
AV. LN
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
        0      527      ***************************
     1000      690      ***********************************
     2000      835      ******************************************
     3000      542      ****************************
     4000      392      ********************
     5000      313      ****************
     6000      245      *************
     7000      171      *********
     8000      155      ********
     9000       96      *****
    10000       66      ****
    11000       27      **
    12000       24      **
    13000        3      *
    14000        2      *

          AV. LN
N           4088
MEAN      3244.5
MEDIAN    2487.1
TMEAN       3046
STDEV     2659.4
SEMEAN        42
MAX        13844
MIN         0.01
Q3          4732
Q1          1314

IN. LN
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
        0      522      ***************************
     1000      713      ************************************
     2000      888      *********************************************
     3000      523      ***************************
     4000      373      *******************
     5000      266      **************
     6000      235      ************
     7000      156      ********
     8000      123      *******
     9000       81      *****
    10000       69      ****
    11000       35      **
    12000       33      **
    13000       13      *
    14000        8      *
    15000        1      *

          IN. LN
N           4039
MEAN      3195.6
MEDIAN    2368.2
TMEAN       2958
STDEV     2741.1
SEMEAN        43
MAX        14840
MIN         2.01
Q3          4529
Q1          1270
```

Figure 8. Data distribution histogram for north luminance (LN)

```
AV. LE
 EACH * REPRESENTS  15 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
         0     476     ********************************
      1000     501     **********************************
      2000     619     ******************************************
      3000     470     ********************************
      4000     334     ***********************
      5000     260     ******************
      6000     233     ****************
      7000     234     ****************
      8000     142     **********
      9000     113     ********
     10000     113     ********
     11000      81     ******
     12000      52     ****
     13000      55     ****
     14000      46     ****
     15000      17     **

            AV. LE
N             3746
MEAN        4083.1
MEDIAN      3075.2
TMEAN         3815
STDEV       3465.9
SEMEAN          57
MAX          14940
MIN           0.13
Q3            6118
Q1            1443

 IN. LE
 EACH * REPRESENTS  15 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
         0     485     *********************************
      1000     546     *************************************
      2000     637     *******************************************
      3000     434     *****************************
      4000     346     ************************
      5000     251     *****************
      6000     201     **************
      7000     170     ************
      8000     156     ***********
      9000     111     ********
     10000      69     ******
     11000      77     ******
     12000      56     ****
     13000      54     ****
     14000      42     ***
     15000      13     *

            IN. LE
N             3672
MEAN        3916.7
MEDIAN      2890.2
TMEAN         3636
STDEV       3449.5
SEMEAN          57
MAX          14999
MIN           2.04
Q3            5756
Q1            1345
```

Figure 9.   Data distribution histogram for east luminance (LE)

```
  AV. LS
   EACH * REPRESENTS  15 OBSERVATIONS

   MIDDLE OF    NUMBER OF
   INTERVAL     OBSERVATIONS
          0       528     ************************************
       1000       521     ***********************************
       2000       435     *****************************
       3000       406     ****************************
       4000       317     **********************
       5000       253     *****************
       6000       196     **************
       7000       165     ***********
       8000       197     **************
       9000       143     **********
      10000       115     ********
      11000       111     ********
      12000       124     *********
      13000        75     *****
      14000        72     *****
      15000        29     **

             AV. LS
N              3709
MEAN         4524.2
MEDIAN       3385.7
TMEAN          4270
STDEV        3940.6
SEMEAN           65
MAX           14996
MIN            0.01
Q3             7206
Q1             1235

  IN. LS
   EACH * REPRESENTS  15 OBSERVATIONS

   MIDDLE OF    NUMBER OF
   INTERVAL     OBSERVATIONS
          0       543     *************************************
       1000       499     **********************************
       2000       506     **********************************
       3000       403     ***************************
       4000       297     ********************
       5000       219     ***************
       6000       220     ***************
       7000       166     ************
       8000       148     **********
       9000       139     **********
      10000       107     ********
      11000       100     *******
      12000        62     ******
      13000        84     ******
      14000        77     ******
      15000        26     **

             IN. LS
N              3616
MEAN         4332.2
MEDIAN       3125.6
TMEAN          4054
STDEV        3892.8
SEMEAN           65
MAX           14982
MIN            2.04
Q3             6630
Q1             1224
```

Figure 10. Data distribution histogram for south luminance (LS)

```
AV. LW
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
     0        466     ********************************
  1000        564     **************************************
  2000        565     **************************************
  3000        482     *********************************
  4000        361     *************************
  5000        267     ******************
  6000        192     *************
  7000        196     **************
  8000        157     ***********
  9000        113     ********
 10000         92     *******
 11000         93     *******
 12000         66     *****
 13000         56     ****
 14000         46     ****
 15000         26     **

             AV. LW
N             3776
MEAN          4033
MEDIAN        3007
TMEAN         3754
STDEV         3535
SEMEAN          58
MAX          14998
MIN              0
Q3            5983
Q1            1341
```

```
IN. LW
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
     0        478     ********************************
  1000        573     ***************************************
  2000        641     *******************************************
  3000        413     ****************************
  4000        346     ************************
  5000        250     *****************
  6000        201     **************
  7000        167     ************
  8000        129     *********
  9000        107     ********
 10000         96     *******
 11000         66     *****
 12000         65     *****
 13000         52     ****
 14000         42     ***
 15000         13     *

             IN. LW
N             3641
MEAN        3864.4
MEDIAN      2750.9
TMEAN         3577
STDEV       3444.7
SEMEAN          57
MAX          14994
MIN           1.99
Q3            5610
Q1            1322
```

Figure 11. Data distribution histogram for west luminance (LW)

```
AV. SN
 EACH * REPRESENTS  30 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
        0      922     *******************************
       40     1311     ********************************************
       80     1164     ***************************************
      120      469     ****************
      160      205     *******
      200       50     **
      240       10     *
      280        4     *
      320        4     *
      360        1     *
      400        1     *

           AV. SN
N            4161
MEAN        61.62
MEDIAN      55.73
TMEAN       58.33
STDEV       47.16
SEMEAN       0.73
MAX        397.10
MIN          0.01
Q3          88.54
Q1          24.15

IN. SN
 EACH * REPRESENTS  30 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
        0      957     ********************************
       40     1336     *********************************************
       80     1166     ***************************************
      120      487     *****************
      160      170     ******
      200       54     **
      240        2     *
      280        1     *
      320        2     *
      360        9     *
      400        1     *

           IN. SN
N            4125
MEAN        60.10
MEDIAN      54.20
TMEAN       56.61
STDEV       47.39
SEMEAN       0.74
MAX        396.87
MIN          0.02
Q3          87.09
Q1          23.00
```

Figure 12. Data distribution histogram for north irradiance (SN)

```
 AV. SS
  EACH * REPRESENTS  20 OBSERVATIONS

  MIDDLE OF     NUMBER OF
  INTERVAL      OBSERVATIONS
        0        823      ******************************************
       50        803      *****************************************
      100        393      ********************
      150        320      ****************
      200        294      ***************
      250        265      **************
      300        219      ***********
      350        273      **************
      400        190      **********
      450        131      *******
      500        100      *****
      550         93      *****
      600         70      ****
      650         45      ***
      700         54      ***
      750         44      ***
      800         18      *

            AV. SS
N            4135
MEAN        196.0
MEDIAN     132.64
TMEAN       179.0
STDEV      192.05
SEMEAN        3.0
MAX         799.3
MIN          0.01
Q3          323.7
Q1           36.0

 IN. SS
  EACH * REPRESENTS  20 OBSERVATIONS

  MIDDLE OF     NUMBER OF
  INTERVAL      OBSERVATIONS
        0        874      ********************************************
       50        761      ***************************************
      100        420      *********************
      150        349      ******************
      200        266      **************
      250        236      ************
      300        185      **********
      350        200      **********
      400        184      **********
      450        139      *******
      500         97      *****
      550         89      *****
      600         72      ****
      650         67      ****
      700         43      ***
      750         64      ****
      800         24      **

            IN. SS
N            4082
MEAN       193.85
MEDIAN     120.54
TMEAN       176.1
STDEV       199.2
SEMEAN        3.1
MAX         799.6
MIN          0.04
Q3          312.6
Q1           32.8
```

Figure 13. Data distribution histogram for south irradiance (SS)

```
 AV. SE
  EACH * REPRESENTS  25 OBSERVATIONS

  MIDDLE OF    NUMBER OF
  INTERVAL     OBSERVATIONS
         0       972     ***************************************
        50      1199     ************************************************
       100       622     *************************
       150       322     *************
       200       216     *********
       250       141     ******
       300       170     *******
       350       123     *****
       400       121     *****
       450        76     ****
       500        60     ***
       550        19     *
       600        35     **
       650        35     **
       700        25     *
       750        12     *
       800         9     *

            AV. SE
N             4159
MEAN         131.6
MEDIAN       70.22
TMEAN        113.3
STDEV        154.5
SEMEAN         2.4
MAX         799.63
MIN           0.01
Q3           175.7
Q1            27.6

 IN. SE
  EACH * REPRESENTS  25 OBSERVATIONS

  MIDDLE OF    NUMBER OF
  INTERVAL     OBSERVATIONS
         0      1015     *****************************************
        50      1202     *************************************************
       100       587     ************************
       150       300     ************
       200       176     ********
       250       165     *******
       300       123     *****
       350       127     ******
       400       126     ******
       450        99     ****
       500        48     **
       550        37     **
       600        44     **
       650        25     *
       700        23     *
       750        20     *
       800         6     *

            IN. SE
N             4125
MEAN        131.71
MEDIAN        66.6
TMEAN        113.0
STDEV       158.21
SEMEAN         2.5
MAX         797.05
MIN           0.03
Q3           171.7
Q1            25.6
```

Figure 14. Data distribution histogram for east irradiance (SE)

```
AV. SW
 EACH * REPRESENTS  25 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
      0      1003     *****************************************
     50      1216     *************************************************
    100       655     ***************************
    150       277     ************
    200       261     ***********
    250       171     *******
    300       180     ********
    350        95     ****
    400       126     ******
    450        79     ****
    500        56     ***
    550        22     *
    600         2     *
    650         1     *
    700         0
    750         1     *

          AV. SW
N          4149
MEAN     116.79
MEDIAN    68.20
TMEAN     103.6
STDEV    126.72
SEMEAN      2.0
MAX      747.62
MIN        0.01
Q3        165.1
Q1         26.1

 IN. SW
 EACH * REPRESENTS  30 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
      0      1025     ***********************************
     50      1255     ******************************************
    100       590     ********************
    150       327     ***********
    200       174     ******
    250       155     ******
    300       122     *****
    350       164     ******
    400       113     ****
    450        86     ***
    500        64     ***
    550        38     **
    600         1     *

          IN. SW
N          4116
MEAN     116.99
MEDIAN    64.66
TMEAN     103.2
STDEV    131.54
SEMEAN      2.1
MAX      577.13
MIN        0.03
Q3        154.0
Q1         25.3
```

Figure 15. Data distribution histogram for west irradiance (SW)

```
 AV. IZ
  EACH * REPRESENTS  20 OBSERVATIONS

  MIDDLE OF     NUMBER OF
  INTERVAL      OBSERVATIONS
        0        871     ********************************************
    10000        759     **************************************
    20000        558     ****************************
    30000        353     ******************
    40000        440     **********************
    50000        303     ****************
    60000        272     **************
    70000        212     ***********
    80000        188     **********
    90000        157     ********
   100000         46     ***
   110000          7     *

           AV. IZ
N            4168
MEAN        30877
MEDIAN      23082
TMEAN       29170
STDEV       27497
SEMEAN        426
MAX        108779
MIN          0.09
Q3          49888
Q1           6751

 IN. IZ
  EACH * REPRESENTS  20 OBSERVATIONS

  MIDDLE OF     NUMBER OF
  INTERVAL      OBSERVATIONS
        0        696     ***********************************
    10000        763     ***************************************
    20000        487     *************************
    30000        421     **********************
    40000        367     *******************
    50000        300     ***************
    60000        232     ************
    70000        195     **********
    80000        162     *********
    90000        174     *********
   100000         93     *****
   110000         16     *
   120000          2     *

           IN. IZ
N            4130
MEAN        31091
MEDIAN      22662
TMEAN       29144
STDEV       28636
SEMEAN        446
MAX        115614
MIN          5.92
Q3          49019
Q1           6605
```

Figure 16. Data distribution histogram for global illuminance (IZ)

```
  AV. IS
   EACH * REPRESENTS  20 OBSERVATIONS

   MIDDLE OF     NUMBER OF
   INTERVAL      OBSERVATIONS
          0       867        ********************************************
       5000       801        *****************************************
      10000       367        *******************
      15000       298        ***************
      20000       270        **************
      25000       231        ************
      30000       217        ***********
      35000       262        **************
      40000       199        **********
      45000       147        ********
      50000        90        *****
      55000        97        *****
      60000        60        ****
      65000        50        ***
      70000        62        ****
      75000        45        ***
      80000        10        *

            AV. IS
N             4113
MEAN         19606
MEDIAN       12527
TMEAN        17970
STDEV        19522
SEMEAN         304
MAX          79927
MIN           0.19
Q3           32611
Q1            3327
```

```
  IN. IS
   EACH * REPRESENTS  20 OBSERVATIONS

   MIDDLE OF     NUMBER OF
   INTERVAL      OBSERVATIONS
          0       886        *********************************************
       5000       794        ****************************************
      10000       422        **********************
      15000       309        ****************
      20000       238        ************
      25000       230        ************
      30000       189        **********
      35000       166        **********
      40000       194        **********
      45000       129        *******
      50000       107        ******
      55000        81        *****
      60000        96        *****
      65000        67        ****
      70000        57        ***
      75000        66        ****
      80000        17        *

            IN. IS
N             4068
MEAN         19591
MEDIAN       11440
TMEAN        17834
STDEV        20331
SEMEAN         319
MAX          79866
MIN           4.27
Q3           32084
Q1            3146
```

Figure 17.   Data distribution histogram for south illuminance (IS)

```
AV. IE
 EACH * REPRESENTS  25 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
       0        895       ************************************
    5000       1129       **********************************************
   10000        664       ***************************
   15000        303       *************
   20000        203       *********
   25000        191       ********
   30000        101       *****
   35000         91       ****
   40000        105       *****
   45000        125       *****
   50000         77       ****
   55000         76       ****
   60000         80       ****
   65000         40       **
   70000         46       **
   75000         11       *

            AV. IE
N             4137
MEAN         14863
MEDIAN        7689
TMEAN        12997
STDEV        17265
SEMEAN         268
MAX          75966
MIN            .03
Q3           20377
Q1            3197

IN. IE
 EACH * REPRESENTS  25 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
       0        903       *************************************
    5000       1190       ************************************************
   10000        607       *************************
   15000        330       **************
   20000        166       *******
   25000         97       ****
   30000         96       ****
   35000        137       ******
   40000        105       *****
   45000         59       ***
   50000        115       *****
   55000         82       ****
   60000         55       ***
   65000         75       ***
   70000         52       ***
   75000         16       *
   80000          1       *

            IN. IE
N             4086
MEAN         14907
MEDIAN        7223
TMEAN        12936
STDEV        17959
SEMEAN         281
MAX          78168
MIN           4.34
Q3           18506
Q1            2981
```

Figure 18. Data distribution histogram for east illuminance (IE)

```
AV. IW
  EACH * REPRESENTS  25 OBSERVATIONS

  MIDDLE OF    NUMBER OF
  INTERVAL     OBSERVATIONS
       0        931     **************************************
    5000       1154     ***********************************************
   10000        681     ****************************
   15000        305     *************
   20000        220     *********
   25000        162     *******
   30000        102     *****
   35000        134     ******
   40000        120     *****
   45000         72     ***
   50000         68     ***
   55000         96     ****
   60000         50     **
   65000         30     **
   70000         39     **
   75000         11     *

             AV. IW
N             4177
MEAN         14151
MEDIAN      7525.4
TMEAN        12305
STDEV        16457
SEMEAN         255
MAX          76007
MIN            .05
Q3           18892
Q1            3116
  IN. IW
  EACH * REPRESENTS  25 OBSERVATIONS

  MIDDLE OF    NUMBER OF
  INTERVAL     OBSERVATIONS
       0        905     *************************************
    5000       1216     *************************************************
   10000        642     **************************
   15000        345     **************
   20000        160     *******
   25000        106     *****
   30000        118     *****
   35000        102     *****
   40000         80     ****
   45000         89     ****
   50000        104     *****
   55000         69     ***
   60000         53     ***
   65000         61     ***
   70000         42     **
   75000         19     *

             IN. IW
N             4113
MEAN         14289
MEDIAN        7189
TMEAN        12313
STDEV        17230
SEMEAN         269
MAX          76984
MIN           4.39
Q3           17086
Q1            3047
```

Figure 19. Data distribution histogram for west illuminance (IW)

```
AV. IN
EACH * REPRESENTS  25 OBSERVATIONS

MIDDLE OF     NUMBER OF
INTERVAL      OBSERVATIONS
     0          803      *********************************
  4000         1115      *********************************************
  8000         1150      **********************************************
 12000          696      ****************************
 16000          331      **************
 20000           59      ***
 24000           12      *
 28000            4      *
 32000            1      *
 36000            3      *
 40000            1      *

            AV. IN
N             4175
MEAN        6984.4
MEDIAN        6396
TMEAN         6726
STDEV       5030.3
SEMEAN          78
MAX          38579
MIN            .11
Q3           10323
Q1            3076

IN. IN
EACH * REPRESENTS  35 OBSERVATIONS

MIDDLE OF     NUMBER OF
INTERVAL      OBSERVATIONS
     0          936      ***************************
  5000         1536      ********************************************
 10000         1029      ******************************
 15000          516      ***************
 20000           96      ***
 25000            2      *
 30000            0
 35000            2      *
 40000            0
 45000            2      *
 50000            9      *
 55000            2      *
 60000            0
 65000            2      *
 70000            2      *

            IN. IN
N             4136
MEAN        7072.6
MEDIAN      6362.3
TMEAN         6682
STDEV       5794.8
SEMEAN          90
MAX          70429
MIN           4.37
Q3           10021
Q1            2925
```

Figure 20. Data distribution histogram for north illuminance (IN)

```
AV. ID
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF     NUMBER OF
 INTERVAL      OBSERVATIONS
        0       652      *********************************
     5000       659      *********************************
    10000       751      **************************************
    15000       707      ************************************
    20000       443      ***********************
    25000       320      ****************
    30000       206      ***********
    35000       152      ********
    40000        94      *****
    45000        64      *****
    50000        42      ***
    55000        24      **
    60000         4      *
    65000         1      *

            AV. ID
N            4139
MEAN        14817
MEDIAN      12528
TMEAN       13897
STDEV       12033
SEMEAN        187
MAX         63334
MIN          0.09
Q3          20969
Q1           5564

 IN. ID
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF     NUMBER OF
 INTERVAL      OBSERVATIONS
        0       645      *********************************
     5000       647      *********************************
    10000       775      ***************************************
    15000       685      ***********************************
    20000       446      ***********************
    25000       294      ***************
    30000       176      *********
    35000       145      ********
    40000       110      ******
    45000        75      ****
    50000        40      **
    55000        31      **
    60000         6      *
    65000         2      *

            IN. ID
N            4079
MEAN        14736
MEDIAN      12303
TMEAN       13749
STDEV       12215
SEMEAN        191
MAX         63291
MIN          1.86
Q3          20697
Q1           5544
```

Figure 21. Data distribution histogram for diffuse illuminance (ID)

```
AV. SRT
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF   NUMBER OF
 INTERVAL    OBSERVATIONS
         0   873   ********************************************
       100   792   ****************************************
       200   533   ***************************
       300   388   ********************
       400   408   *********************
       500   330   *****************
       600   280   **************
       700   239   ************
       800   188   **********
       900   133   *******
      1000    19   *
```

```
          AV. SRT
N           4183
MEAN      301.55
MEDIAN    225.54
TMEAN      285.9
STDEV      264.5
SEMEAN       4.1
MAX       1009.4
MIN          .01
Q3         492.3
Q1          67.7
```

```
IN. SRT
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF   NUMBER OF
 INTERVAL    OBSERVATIONS
         0   914   **********************************************
       100   819   *****************************************
       200   498   *************************
       300   430   **********************
       400   351   ******************
       500   294   ***************
       600   240   ************
       700   216   ***********
       800   171   *********
       900   179   *********
      1000    48   ***
      1100     6   *
      1200     2   *
```

```
          IN. SRT
N           4168
MEAN       301.2
MEDIAN     210.9
TMEAN      282.9
STDEV      277.4
SEMEAN       4.3
MAX       1185.6
MIN          0.1
Q3         481.4
Q1          62.7
```

Figure 22. Data distribution histogram for global irradiance (SRT)

```
AV. SRD
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
         0    629    ********************************
        50    757    **************************************
       100    863    ********************************************
       150    593    ******************************
       200    392    ********************
       250    317    ****************
       300    234    ************
       350    172    *********
       400    123    *******
       450     65    ****
       500     24    **
       550      6    *
       600      1    *
```

```
        AV. SRD
N          4176
MEAN     143.13
MEDIAN   114.12
TMEAN     135.0
STDEV     115.8
SEMEAN      1.8
MAX       590.5
MIN        0.01
Q3        211.6
Q1         54.2
```

```
IN. SRD
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
         0    650    *********************************
        50    759    **************************************
       100    879    ********************************************
       150    578    *****************************
       200    383    ********************
       250    298    ***************
       300    219    ***********
       350    165    *********
       400    114    ******
       450     54    ***
       500     39    **
       550     14    *
       600      4    *
```

```
        IN. SRD
N          4156
MEAN     141.49
MEDIAN    110.6
TMEAN     132.5
STDEV    117.96
SEMEAN      1.8
MAX      580.44
MIN        0.09
Q3        205.9
Q1         52.4
```

Figure 23. Data distribution histogram for diffuse irradiance (SRD)

```
AV. CR
 EACH * REPRESENTS  30 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0         1      *
     0.1       106      ****
     0.2       445      ***************
     0.3       381      *************
     0.4       334      ************
     0.5       323      ***********
     0.6       269      *********
     0.7       285      **********
     0.8       265      *********
     0.9       367      *************
     1.0      1352      **********************************************

          AV. CR
N          4126
MEAN      0.6655
MEDIAN    0.7200
TMEAN     0.6760
STDEV     0.3072
SEMEAN    0.0048
MAX       1.0000
MIN       0.0400
Q3        1.0000
Q1        0.3700

IN. CR
 EACH * REPRESENTS  35 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0         2      *
     0.1       117      ****
     0.2       466      **************
     0.3       394      ************
     0.4       330      **********
     0.5       266      ********
     0.6       211      *******
     0.7       188      ******
     0.8       187      ******
     0.9       304      *********
     1.0      1600      **********************************************

          IN. CR
N          4069
MEAN      0.6767
MEDIAN    0.7700
TMEAN     0.6886
STDEV     0.3215
SEMEAN    0.0050
MAX       1.0000
MIN       0.0400
Q3        1.0000
Q1        0.3600
```

Figure 24.   Data distribution histogram for cloud ratio (CR)

```
 AVER. TO
  EACH * REPRESENTS  30 OBSERVATIONS

  MIDDLE OF   NUMBER OF
  INTERVAL    OBSERVATIONS
      -10       16   *
        0      431   ***************
       10      127   *****
       20      425   ***************
       30      908   *******************************
       40     1202   *****************************************
       50     1111   **************************************
       60     1325   *********************************************
       70     1376   **********************************************
       80      845   *****************************
       90      321   ***********
      100       25   *


        AVER. TO
N           8112
MEAN       51.13
MEDIAN     53.54
TMEAN      51.91
STDEV      22.64
SEMEAN      0.25
MAX        99.21
MIN       -14.04
Q3         68.67
Q1         35.95

 INST. TO
  EACH * REPRESENTS  30 OBSERVATIONS

  MIDDLE OF   NUMBER OF
  INTERVAL    OBSERVATIONS
      -10       14   *
        0      430   ***************
       10      125   *****
       20      414   **************
       30      906   *******************************
       40     1200   ****************************************
       50     1106   *************************************
       60     1317   ********************************************
       70     1394   ***********************************************
       80      836   ****************************
       90      336   ************
      100       29   *


        INST. TO
N           8107
MEAN       51.22
MEDIAN     53.60
TMEAN      52.00
STDEV      22.59
SEMEAN      0.25
MAX        99.10
MIN       -10.30
Q3         68.70
Q1         36.10
```

Figure 25. Data distribution histogram for outdoor temperature (TO)

```
AV. IBN
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
      0      416      ****************************
  10000      505      **********************************
  20000      333      ***********************
  30000      267      ******************
  40000      316      **********************
  50000      298      ********************
  60000      297      ********************
  70000      269      ********************
  80000      197      **************
  90000       82      ******
 100000       16      **
 110000        4      *
 120000        0
 130000        1      *

            AV. IBN
N              3021
MEAN          36720
MEDIAN        34672
TMEAN         35821
STDEV         27053
SEMEAN          492
MAX          128086
MIN            0.42
Q3            59902
Q1            11150

IN. IBN
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
      0      516      ***********************************
  10000      464      *********************************
  20000      236      ****************
  30000      216      ***************
  40000      242      *****************
  50000      276      *******************
  60000      296      ********************
  70000      296      ********************
  80000      219      ***************
  90000      104      *******
 100000       32      ***
 110000        2      *
 120000        1      *

            IN. IBN
N              2920
MEAN          37399
MEDIAN        35676
TMEAN         36455
STDEV         28976
SEMEAN          536
MAX          118333
MIN               3
Q3            62364
Q1             9597
```

Figure 26. Data distribution histogram for direct normal (beam) illuminance (IBN)

```
AV SBN
 EACH * REPRESENTS  15 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
       0      530     ************************************
     100      359     ************************
     200      296     ********************
     300      289     ********************
     400      306     *********************
     500      281     *******************
     600      266     ******************
     700      271     *******************
     800      256     ******************
     900      120     ********
    1000        4     *
    1100        1     *

            AV SBN
N            2981
MEAN        374.8
MEDIAN      356.5
TMEAN       367.3
STDEV       280.6
SEMEAN        5.1
MAX        1118.2
MIN          0.03
Q3          614.7
Q1          103.7

 IN SBN
 EACH * REPRESENTS  15 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
       0      640     *******************************************
     100      266     ******************
     200      186     *************
     300      223     ***************
     400      226     ****************
     500      240     ****************
     600      289     ********************
     700      310     *********************
     800      305     *********************
     900      123     *********
    1000        3     *
    1100        1     *
    1200        0
    1300        1     *

            IN SBN
N            2817
MEAN        390.6
MEDIAN      391.1
TMEAN       384.7
STDEV       300.0
SEMEAN        5.7
MAX        1268.8
MIN          0.01
Q3          561.8
Q1           67.5
```

Figure 27. Data distribution histogram for direct normal (beam) irradiance (SBN)

```
AV. E1
 EACH * REPRESENTS  35 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0       330      **********
     0.5      1602      **********************************************
     1.0       532      ****************
     1.5       245      *******
     2.0       125      ****
     2.5        78      ***
     3.0        46      **
     3.5        28      *
     4.0        11      *
     4.5         4      *
     5.0         5      *
     5.5         2      *
     6.0      1056      *******************************

          AV. E1
N           4064
MEAN       2.153
MEDIAN     0.820
TMEAN      2.052
STDEV      2.365
SEMEAN     0.037
MAX        6.000
MIN        0.010
Q3         6.000
Q1         0.400
```

```
IN. E1
 EACH * REPRESENTS  35 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0       303      *********
     0.5      1585      **********************************************
     1.0       431      *************
     1.5       225      *******
     2.0       133      ****
     2.5        91      ***
     3.0        61      **
     3.5        29      *
     4.0        21      *
     4.5        10      *
     5.0        13      *
     5.5         7      *
     6.0      1143      *********************************

          IN. E1
N           4052
MEAN       2.305
MEDIAN     0.850
TMEAN      2.220
STDEV      2.428
SEMEAN     0.038
MAX        6.000
MIN        0.010
Q3         6.000
Q1         0.390
```

Figure 28. Data distribution histogram for atmospheric extinction coefficient E1

```
AV. E2
 EACH * REPRESENTS  30 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0        323     ***********
     0.5       1497     **************************************************
     1.0        536     ******************
     1.5        241     *********
     2.0        124     *****
     2.5         73     ***
     3.0         67     ***
     3.5         37     **
     4.0         35     **
     4.5         13     *
     5.0         10     *
     5.5         10     *
     6.0       1107     *************************************

           AV. E2
N            4075
MEAN        2.277
MEDIAN      0.900
TMEAN       2.189
STDEV       2.398
SEMEAN      0.038
MAX         6.000
MIN         0.010
Q3          6.000
Q1          0.400

IN. E2
 EACH * REPRESENTS  35 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0        277     ********
     0.5       1542     *********************************************
     1.0        411     ************
     1.5        149     *****
     2.0        115     ****
     2.5         92     ***
     3.0         66     **
     3.5         45     **
     4.0         32     *
     4.5         35     *
     5.0         21     *
     5.5         11     *
     6.0       1287     *************************************

           IN. E2
N            4083
MEAN        2.523
MEDIAN      0.930
TMEAN       2.462
STDEV       2.504
SEMEAN      0.039
MAX         6.000
MIN         0.010
Q3          6.000
Q1          0.390
```

Figure 29. Data distribution histogram for atmospheric extinction coefficient E2

```
AV. TR1
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0        39      **
     0.1       450      *******************************
     0.2       474      *********************************
     0.3       573      ***************************************
     0.4       966      *******************************************************************
     0.5       631      **********************************************************
     0.6       305      **********************
     0.7        98      *****
     0.8        20      *
     0.9        10      *
     1.0         4      *

          AV. TR1
N            3770
MEAN       0.3646
MEDIAN     0.3900
TMEAN      0.3631
STDEV      0.1644
SEMEAN     0.0027
MAX        0.9900
MIN        0.0100
Q3         0.4700
Q1         0.2400

IN. TR1
 EACH * REPRESENTS  20 OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     0.0        72      ****
     0.1       484      **********************************
     0.2       500      **********************************
     0.3       606      *******************************************
     0.4       912      ***************************************************************
     0.5       669      ***********************************************
     0.6       285      *********************
     0.7       136      *******
     0.8        50      ***
     0.9        26      **
     1.0         5      *

          IN. TR1
N            3749
MEAN       0.3593
MEDIAN     0.3700
TMEAN      0.3544
STDEV      0.1796
SEMEAN     0.0029
MAX        0.9900
MIN        0.0100
Q3         0.4700
Q1         0.2200
```

Figure 30. Data distribution histogram for downward transfer ratio TR1

```
  AV. TR2
   EACH * REPRESENTS  30 OBSERVATIONS

   MIDDLE OF    NUMBER OF
   INTERVAL     OBSERVATIONS
       0.0        70     ***
       0.1       462     ****************
       0.2       524     ******************
       0.3      1271     *******************************************
       0.4      1067     ************************************
       0.5       379     *************
       0.6        46     **
       0.7        12     *
       0.8         8     *
       0.9         7     *
       1.0         2     *

           AV. TR2
N             3870
MEAN        0.3030
MEDIAN      0.3200
TMEAN       0.3078
STDEV       0.1296
SEMEAN      0.0021
MAX         0.9900
MIN         0.0100
Q3          0.3900
Q1          0.2300

  IN. TR2
   EACH * REPRESENTS  30 OBSERVATIONS

   MIDDLE OF    NUMBER OF
   INTERVAL     OBSERVATIONS
       0.0       102     ****
       0.1       496     *****************
       0.2       561     *******************
       0.3      1261     *******************************************
       0.4       909     *******************************
       0.5       341     ************
       0.6       126     *****
       0.7        46     **
       0.8        16     *
       0.9         3     *
       1.0         3     *

           IN. TR2
N             3868
MEAN        0.3053
MEDIAN      0.3100
TMEAN       0.3012
STDEV       0.1439
SEMEAN      0.0023
MAX         0.9900
MIN         0.0100
Q3          0.3900
Q1          0.2200
```

Figure 31. Data distribution histogram for downward transfer ratio TR2

Abbreviated Appendix A

NBSIR 84-2859
The NBS Daylight Availability Database

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INSTANTANEOUS DATA

DAILY AVERAGE FOR MONTH

	MONTHS												ANNUAL		
	1	2	3	4	5	6	7	8	9	10	11	12	HOURLY AVERAGE	DAILY AVERAGE TOTAL	UNIT
LZ	13247.	23223.	37680.	47324.	67594.	100481.	100381.	77075.	41120.	28211.	26545.	14385.	3932.	48012.	CD/M2
LN	19174.	25092.	35476.	45408.	49165.	66402.	60378.	50728.	30036.	23953.	22596.	14702.	3029.	36856.	CD/M2
LE	18494.	33070.	51192.	91185.	83906.	88485.	107318.	106075.	56733.	35284.	30761.	19357.	5047.	60032.	CD/M2
LS	32022.	47530.	62155.	81814.	78880.	85081.	90921.	92978.	64078.	60212.	62801.	47155.	5585.	67123.	CD/M2
LW	22194.	34971.	52138.	75187.	84498.	91539.	91413.	99393.	50980.	36600.	30284.	15736.	4857.	56939.	CD/M2
SN	343.	448.	595.	867.	1051.	1064.	1284.	933.	472.	373.	475.	379.	56.	689.	W/M2
SS	1583.	2382.	2151.	2663.	2365.	1967.	2383.	2385.	2129.	2086.	2245.	2129.	179.	2203.	W/M2
SE	739.	1087.	1166.	2148.	2242.	1892.	2519.	2012.	1309.	1054.	1001.	981.	122.	1509.	W/M2
SW	700.	966.	1329.	1897.	2006.	1764.	2066.	1705.	1169.	888.	861.	732.	108.	1338.	W/M2
IZ	149477.	240379.	299038.	483863.	562579.	497937.	619191.	516098.	344789.	242275.	184142.	152054.	28694.	356680.	LUX
IS	158564.	248353.	228794.	281864.	228644.	202220.	210082.	240325.	212756.	208176.	220311.	218742.	18059.	221376.	LUX
IE	87001.	138337.	141263.	239348.	259400.	230534.	244138.	229922.	167174.	123918.	96218.	80457.	13747.	169280.	LUX
IW	84473.	125834.	169686.	230119.	245303.	218631.	253040.	202613.	142624.	113420.	101879.	76059.	13184.	163257.	LUX
IN	41604.	60993.	79875.	109451.	119269.	140773.	139218.	103829.	61352.	43521.	43253.	34715.	6528.	81256.	LUX
ID	90319.	130904.	161452.	198378.	255844.	263780.	254505.	205985.	150506.	105761.	106849.	84843.	13587.	166967.	LUX
SRT	1449.	2392.	3140.	4894.	5632.	4990.	5747.	4658.	3014.	2549.	1986.	1503.	278.	3487.	W/M2
SRD	769.	1148.	1562.	1999.	2241.	2678.	2553.	2304.	1404.	1139.	1092.	750.	131.	1633.	W/M2
CR	682.	758.	873.	793.	745.	983.	850.	807.	661.	584.	777.	669.	62.	765.	PCT
TO	559.	757.	991.	1035.	1325.	1668.	1765.	1545.	1193.	1121.	1135.	748.	51.	1154.	DEG.F
IBN	151218.	222293.	240408.	416481.	407868.	313121.	493377.	449448.	327685.	268035.	178217.	177525.	37399.	303344.	LUX
SBN	1699.	2575.	2605.	4412.	4818.	3243.	4315.	3421.	2689.	2889.	2093.	2001.	391.	3056.	W/M2

HOURLY AVERAGES

E1	3.29	3.17	2.85	2.37	1.93	2.87	0.95	1.15	2.10	2.57	2.51	2.85	2.38
E2	2.71	3.03	3.12	2.29	1.71	2.69	1.88	2.24	3.26	2.74	2.39	2.02	2.51
TR1	0.29	0.31	0.29	0.34	0.42	0.34	0.39	0.37	0.31	0.26	0.31	0.29	0.33
TR2	0.24	0.27	0.28	0.31	0.35	0.31	0.34	0.31	0.24	0.25	0.29	0.24	0.28

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AVERAGE DATA

DAILY AVERAGE FOR MONTH

	MONTHS 1	2	3	4	5	6	7	8	9	10	11	12	ANNUAL HOURLY AVERAGE	ANNUAL DAILY AVERAGE TOTAL	UNIT
ALZ	12786.	23912.	36174.	47008.	67748.	98169.	98586.	78456.	41813.	28858.	25785.	14032.	3864.	47676.	CD/M2
ALN	17472.	24747.	38090.	46347.	49588.	66369.	60057.	52513.	29982.	23490.	22339.	14387.	3008.	37051.	CD/M2
ALE	17527.	32198.	52454.	83808.	87946.	100171.	99770.	107110.	56288.	36397.	30633.	18905.	4940.	60143.	CD/M2
ALS	33058.	51912.	68386.	84067.	79389.	85657.	90679.	94846.	66385.	57084.	66098.	45186.	5546.	68527.	CD/M2
ALW	22385.	32766.	51373.	72038.	89218.	94932.	97586.	99958.	51706.	35484.	30040.	15697.	4749.	57620.	CD/M2
ASN	406.	492.	661.	1002.	1044.	1070.	1273.	929.	470.	374.	468.	378.	57.	712.	W/M2
ASS	1696.	2481.	2333.	2773.	2379.	1992.	2374.	2381.	2096.	2044.	2283.	2207.	181.	2251.	W/M2
ASE	752.	1098.	1185.	2167.	2305.	1890.	2571.	2037.	1267.	1096.	981.	964.	122.	1523.	W/M2
ASW	706.	975.	1401.	1905.	1955.	1813.	2040.	1722.	1171.	927.	835.	732.	108.	1346.	W/M2
AIZ	146876.	240880.	313385.	494328.	558900.	508146.	616416.	517671.	338459.	236166.	178574.	151347.	28516.	357485.	LUX
AIS	165705.	254738.	241016.	289410.	228003.	204849.	210571.	240549.	207941.	201833.	226200.	219693.	18097.	224001.	LUX
AIE	88119.	141052.	154173.	246726.	260267.	232411.	244681.	230194.	162668.	120045.	95240.	80344.	13725.	170805.	LUX
AIW	85783.	123538.	179782.	238792.	240094.	224975.	248545.	205113.	141607.	108394.	101105.	76678.	13072.	164194.	LUX
AIN	41857.	59608.	80086.	111493.	118246.	140657.	137296.	103555.	61274.	42911.	43028.	34645.	6454.	80999.	LUX
AID	90898.	132594.	172379.	213583.	257457.	271574.	257810.	207022.	150544.	107247.	105222.	83183.	13677.	170349.	LUX
ASRT	1523.	2482.	3181.	5047.	5549.	5120.	5716.	4652.	2940.	2565.	1891.	1490.	279.	3504.	W/M2
ASRD	792.	1154.	1704.	2152.	2263.	2681.	2559.	2309.	1422.	1133.	1054.	734.	132.	1660.	W/M2
ACR	689.	743.	856.	807.	717.	940.	822.	799.	663.	609.	802.	712.	61.	763.	PCT
ATO	561.	754.	980.	1030.	1325.	1667.	1768.	1543.	1191.	1123.	1134.	748.	51.	1152.	DEG.F
AIBN	151278.	227401.	264580.	434456.	416455.	320328.	492444.	455590.	312476.	259778.	174770.	193306.	36720.	308145.	LUX
ASBN	1712.	2784.	2691.	4465.	4743.	3404.	4338.	3466.	2577.	2948.	2011.	2185.	375.	3103.	W/M2

HOURLY AVERAGES

	1	2	3	4	5	6	7	8	9	10	11	12	ANNUAL HOURLY AVERAGE
AE1	3.06	2.94	2.57	2.01	1.75	2.54	0.92	1.12	2.15	2.56	2.46	2.66	2.23
AE2	2.76	2.66	2.87	1.94	1.53	2.24	1.58	1.97	3.17	2.53	2.48	2.06	2.32
ATR1	0.29	0.33	0.32	0.36	0.41	0.35	0.39	0.37	0.30	0.27	0.30	0.31	0.33
ATR2	0.24	0.28	0.29	0.33	0.34	0.32	0.33	0.31	0.23	0.25	0.28	0.26	0.29

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9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP) Naval Civil Eng. Lab., Port Hueneme, CA 93043 - Nat'l Fenestration Council, 3310 Harrison St., Topeka, KS 66611 - Naval Facilities Eng. Command, U.S. Navy, Washington, DC 20390 - Directorate of Civil Eng., U.S. Air Force, Washington, DC 20330 - Office of Chief of Engineers, U.S. Army, Washington, DC 20314

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report presents an annual database containing hourly measurements of solar radiation, illumination, sky luminance and ambient air temperature. The measurements were made at the National Bureau of Standards, Gaithersburg, Maryland (77° west longitude, 38.5° north latitude). Both instantaneous hourly and integrated average hourly measurements are included, as are daily, monthly and annual average and totals. For each measured quantity, a histogram of the distribution of the data is presented for the year. The data measurement, collection and analysis system is described.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

daylight availability; irradiance; luminance; sky illuminance, solar radiation, weather data

13. AVAILABILITY

☒ Unlimited
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